

64501

Reference Soil

892.9 grams

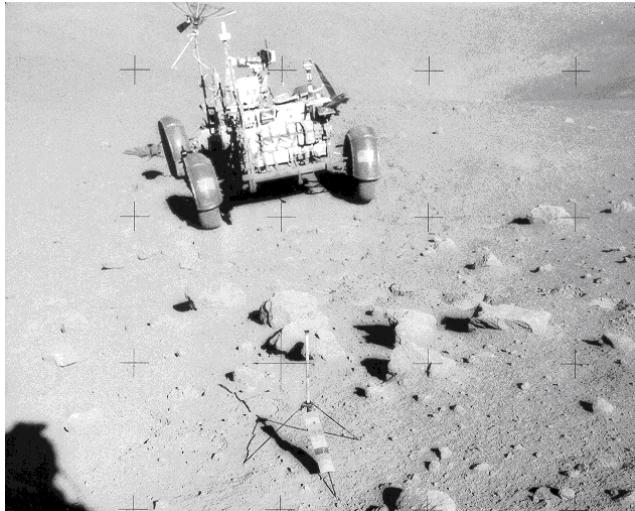


Figure 1: Blocky sample area in double crater near rim of Cinco a. Region of rake sample and soil sample 64500. AS16-110-17948.

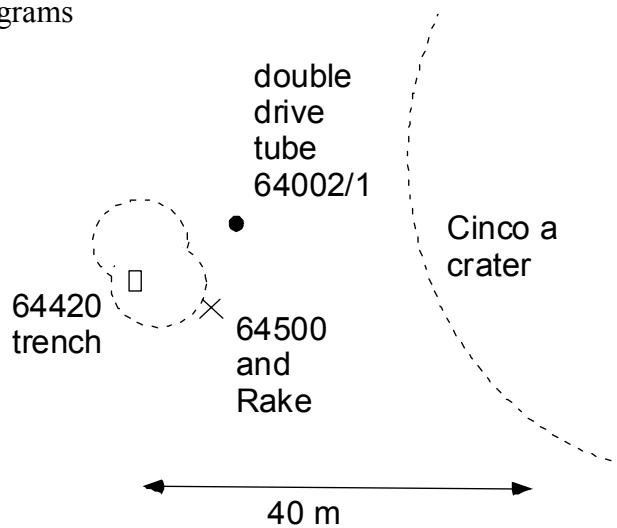


Figure 2: Location of samples at station 4, Apollo 16, on Stone Mountain, Apollo 16.

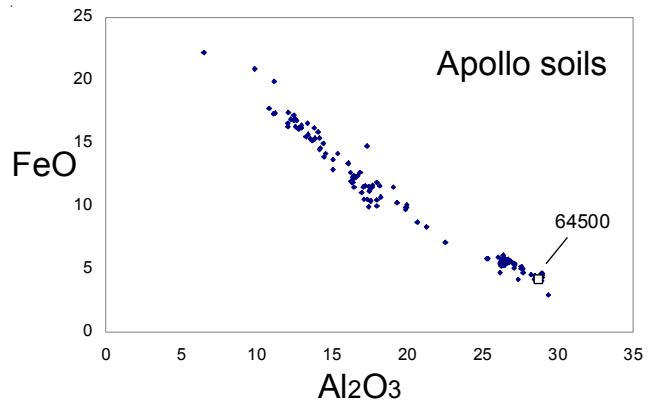


Figure 3: Chemical composition of all lunar soils including Apollo 16.

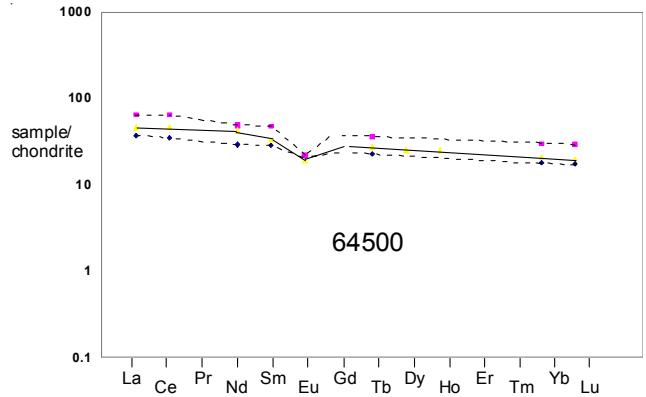


Figure 4: Normalized rare-earth-element diagram for Apollo 16 soils.

Soils 64500 and 64420 are typical of mature Apollo 16 soils. They are aluminous (figure 3) and have high agglutinate content (~ 50 %). One might speculate that the 15 meter crater (Cinco a) was about 300 m.y. old, while the small doublet crater and rocky area was caused by secondary material from South Ray Crater 2 m.y. ago.

Modal content of soil 64501.

From Papike et al. 1982

	1000-90 microns
Agglutinates	29.1
dark matrix bx.	13.9
Mare basalt	0.3
Feldspathic basalt	1.6
Light matrix breccia	2.1
Anorthositic	5
Poikilitic	8.3
Plagioclase	32.1
Olivine and Pyroxene	1
Glass other	6.7

Modal content of soils 64501.

From Heiken et al. 1973.

	150 – 90 micron
Agglutinates	51.6
Basalt	0
Breccia	21
Anorthositic	3
Norite	0.3
Plagioclase	20
Pyroxene	0.6
Glass other	3

Mode for 64501.

From Houck 1982

	29.2
Agglutinate	29.2
Breccias	26.1
Mare basalt	0
Anorthositic	1
Plagioclase	33
Pyroxene	2.5
Olivine	0.3
Opaques	0.4
Silica	0
Glass, other	6.8

Petrography

64500 was considered one of the ‘reference soils’ by the Highland Initiative (Labotka et al. 1980). Morris (1978) reported that 64500 was a mature soil with index $\text{Is}/\text{FeO} = 61$. Heiken et al. (1973) found 51% agglutinates in the 90-150 micron size range while Houck (1982) determined an average of ~ 29 % agglutinate overall. Modal mineralogy by various authors differ because of different categories used.

Glass (1976) studied the glass particles in 64501 and found 5% were mare component, and a few were granitic in composition. However, he did not report a group called ‘highland basalt’, as did Ridley et al. (1973) for 60501. Kempa and Papike (1980) also

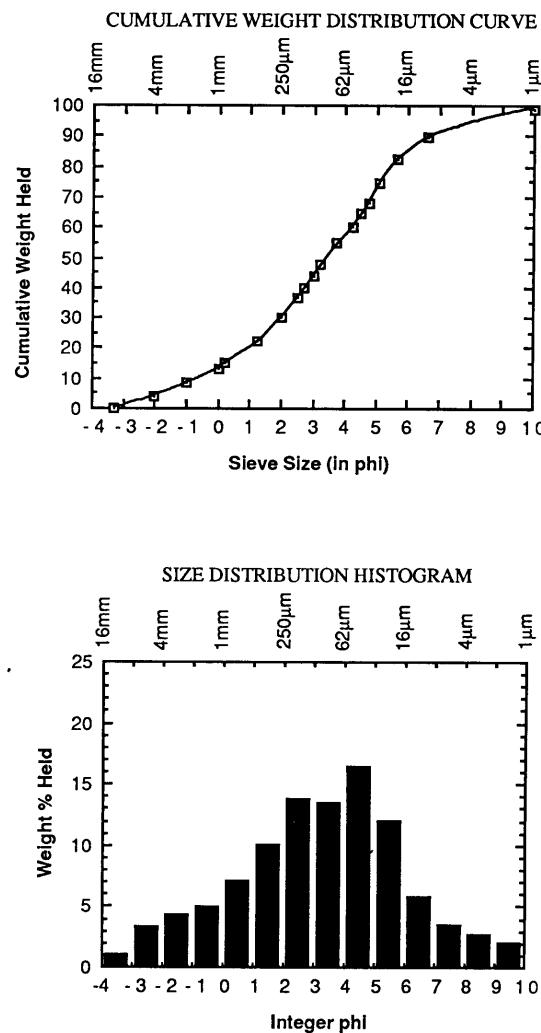


Figure 5: Grain size distribution for 64501 (from Graf 1993, from data by Butler et al. 1973).

analyzed a large number of glass particles from 64501 (figure 7).

Mixing model calculations indicate that this soil is ~ 66 % anorthositic, ~ 30 % low-K Fra Mauro (melt rock) and ~ 4 % mare (Kempa et al. 1980) – all materials found in the soil. Trace amounts of granitic material and high-alumina, silica-poor glass have also been reported.

Butler et al. (1973), Heiken et al. (1973) and Graf (1993) reported the grain size analysis (figure 5).

Mineralogy

Mineral compositions were determined by Kempa and Papike (1980) and Labotka et al. (1980) with about

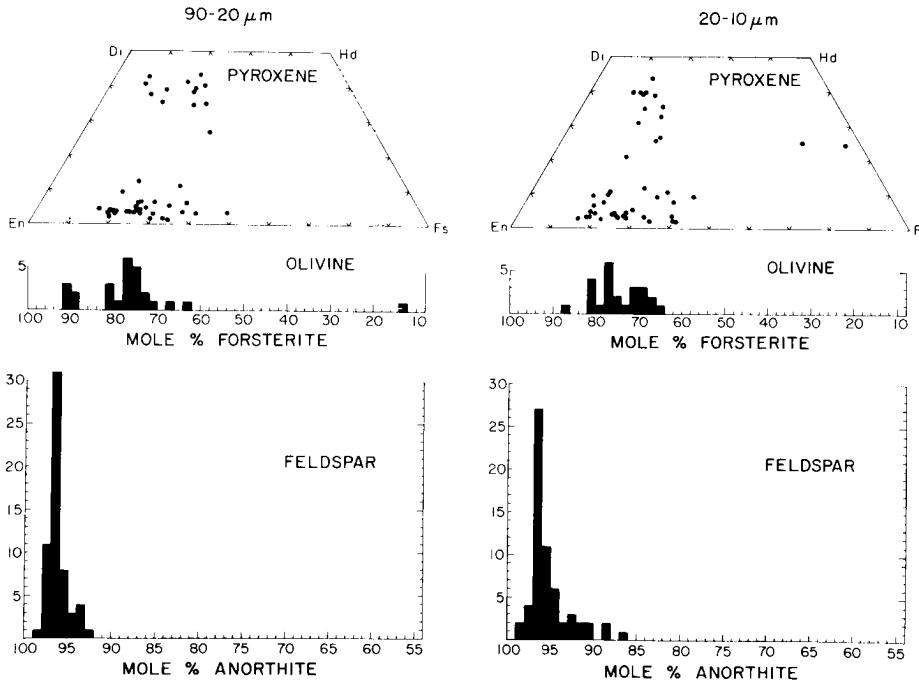


Figure 6: Composition of mineral grains in 64501 (from Labotka et al. 1980).

half of the pyroxene showing mare composition (figure 6).

Rake Samples:

Table 2 lists 11 walnuts (>1 cm) found in 64500, while Table 3 lists 30 rake samples from adjacent soil area. Phinney and Lofgren (1973) initially described the rake samples, while Marvin (1972) described the coarse fine particles. Simonds et al. (1973) described several poikilitic rake samples from this soil and Gooley et al. (1973) studied the cooling history as recorded by metal particles. Korotev (1987) analyzed the high Ni, Ir and Au contents of the noritic impact melt samples, finding that an iron meteorite must have been involved. Turner and Cadogen (1975) determined a radiometric Ar/Ar age of 3.97 b.y., with exposure age of 370 m.y., for poikilitic rake sample 64567.

Chemistry

The chemical composition of 64501 is similar to that of the nearby trench soils 64421 and the double drive tube 64002 – 1 (table 1). Laul and Papike (1980) analyzed bulk soil and several grain size separates for the “reference soils” including 64501. Chemical analyses for rake samples from this location are tabulated in table 4. Basu and McKay (1985) studied the composition of agglutinate glass and See et al.

(1986) studied the composition of large glass splashes at Apollo 16.

Korotev (1981) discussed the close chemical comparison of 64501 with that of dilithologic anorthositic breccias 64475 and 64548.

Muller (1973) determined 96 ppm nitrogen, but I can't find analyses for carbon for this soil.

Radiogenic age dating

Jessberger et al. (1977) reported Ar/Ar ages for rake samples from 64535 and 64536 (3.8 – 4.1 b.y.).

Cosmogenic isotopes and exposure ages

Clark and Keith (1973) determined the cosmic-ray-induced activity of ^{26}Al = 160 dpm/kg., ^{22}Na = 44 dpm/kg., ^{54}Mn = 6 dpm/kg. and ^{46}Sc = 2.2 dpm/kg. Kirsten et al. (1973) reported a Ne exposure age of 210 m.y.

Jessberger et al. (1977) determined the exposure age of some of the rake samples from this soil. In particular, 64535 was found to be 1.9 m.y. old, consistent with excavation by South Ray Crater (see section on 64535). The egg, 64455, from this site was also found to be 2 m.y.

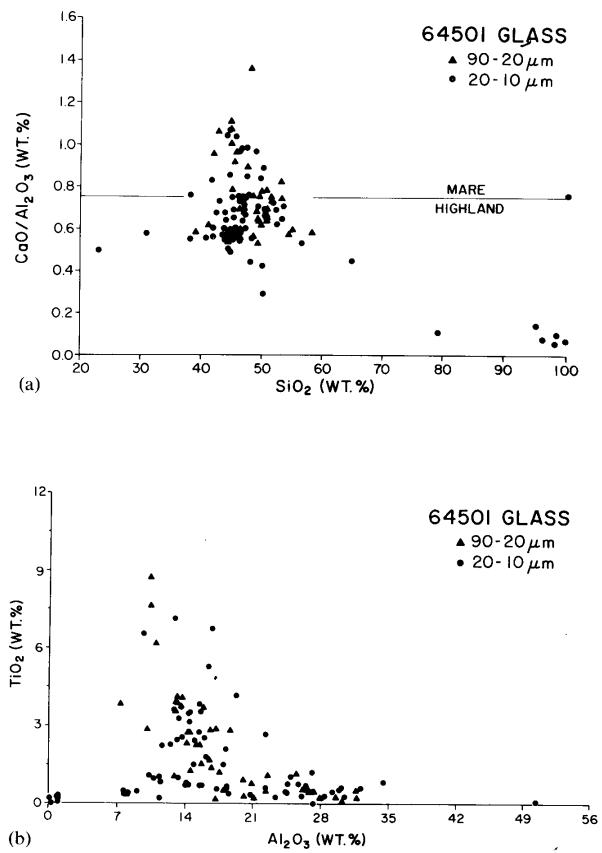


Figure 7: Composition of glass particles in 64501 (Kempa and Papike 1980).

Other Studies

Kirsten et al. (1973) reported the rare gas content and isotopic ratios. From this you can also estimate maturity.

Table 1. Chemical composition of 64500.

reference weight	Papike 82					Korotev91	other for comparison		
	Haskin73	Laul 80	Morrison73	Muller75	Finkelman75		Korotev 84	Wanke73	
SiO ₂ %	45.2	45.3	(a)				64001 - 2	64421	
TiO ₂	0.53	0.37	(a) 0.57	(b)			26-60	45.14	
Al ₂ O ₃	27.4	27.7	(a) 26.8	(b) 28.1				0.53	
FeO	4.16	4.2	(a) 4.25	(b) 4.36				27.8	
MnO	0.057	0.056	(a) 0.057	(b)				0.06	
MgO	4.27	4.9	(a) 6.35	(b) 5.64				5.24	
CaO	16.6	17.2	(a) 19.17	(b) 15.7				15.81	
Na ₂ O	0.47	0.44	(a) 0.48	(b) 0.48	Clark 73		0.45	(a)	0.44
K ₂ O	0.111	0.1	(a) 0.111	(b) 0.11	0.106 (c)			0.1	
P ₂ O ₅			0.14	(b)					
S %			0.045	(b)					
<i>sum</i>									
Sc ppm	10.4	(a) 8		7.17	(b)	7	11	8	7.48 (a) 10.14 (a) 7.9
V		20		10	(b)	16	23	14	
Cr		616	(a) 570		(b)			581	(a) 774 (a) 620
Co	21	(a) 19.5		29	(b)	12	30	9	20.9 (a) 28 (a) 25
Ni	290	(a) 300		340	(b)	270	610	220	311 (a) 404 (a) 330
Cu				5.9	(b)	6	10	30	
Zn	26	(a) 20		(b)		7	10	40	
Ga	5.2	(a) 4.5		(b)		2	3	4	
Ge ppb									
As									
Se									
Rb	2.5	(a) 2.2		(b) 2.6		1	1	2	
Sr		170	(a) 158	(b) 161		140	170	180	167 (a) 181 (a) 160
Y		40	(b)			32	44	38	40
Zr		218	(b)			100	127	110	129 (a) 215 (a) 174
Nb		11	(b)			10	10	10	9.5
Mo									
Ru									
Rh									
Pd ppb									
Ag ppb									
Cd ppb									
In ppb				330	(b)				
Sn ppb									
Sb ppb									
Te ppb									
Cs ppm	0.11	(a) 0.02		(b) 0.12			0.1	(a)	
Ba		130	(a) 206	(b) 114			124	(a)	145 (a) 115
La	11.7	(a) 10.8	(a) 10	(b) 10.3			10.8	(a)	13 (a) 12.3
Ce	30.3	(a) 28	(a) 29	(b)			28.1	(a)	35.2 (a) 35
Pr			4.1	(b)					
Nd	20.3	(a) 19	(a) 18	(b)			20	(a)	21.8 (a)
Sm	5.48	(a) 4.79	(a) 5.5	(b)			5.06	(a)	6.21 (a) 5.7
Eu	1.18	(a) 1.05	(a) 1.2	(b)			1.11	(a)	1.16 (a) 1.14
Gd	7.4	(a)	5.4	(b)					
Tb	1.18	(a) 1	(a) 1.1	(b)			0.98	(a)	1.37 (a) 1.1
Dy	7.3	(a) 6	(a) 6.9	(b)					6.8
Ho	1.5	(a) 1.4	(a) 1.2	(b)					1.6
Er	4.4	(a)	4.2	(b)					
Tm		0.55	(a) 0.5	(b)					
Yb	3.74	(a) 3.4	(a) 4	(b)			3.51	(a)	4.41 (a) 4
Lu	0.54	(a) 0.49	(a) 0.57	(b)			0.471	(a)	0.65 (a) 0.57
Hf	4.7	(a) 3.3	(a) 4.4	(b)			3.65	(a)	4.76 (a) 4
Ta		0.45	(a)				0.44	(a)	0.56 (a) 0.5
W ppb									
Re ppb									
Os ppb									
Ir ppb							8.8	(a)	13.8 9
Pt ppb									
Au ppb					Clark 73		13.9	(a)	6.7 7.5
Th ppm		1.85	(a) 2.6		1.86 (c)		1.76	(a)	2.25 (a)
U ppm		0.4	(a) 0.54	(b) 0.43	0.49 (c)		0.54	(a)	0.54 (a)

technique: (a) INAA, (b) multiple, (c) raditation counting

Table 2: Walnut Samples from 64500 (DB396)

	weight	Ryder's term	ref
64505	5.392	breccia	
64506	5.079	impact melt	
64507	4.474	breccia	
64508	4.168	breccia	
64509	3.15	breccia	
64515	3.761	impact melt	
64516	2.929	cataclastic anorthosite	
64517	1.546	breccia	
64518	1.49	impact melt	
64519	1.124	cataclastic anorthosite	
64525	1.1	cataclastic anorthosite	
	these are > 10 mm		
64504	24 g	4 to 10 mm peanuts	
	see also table 3 for rake samples, same location		

ref

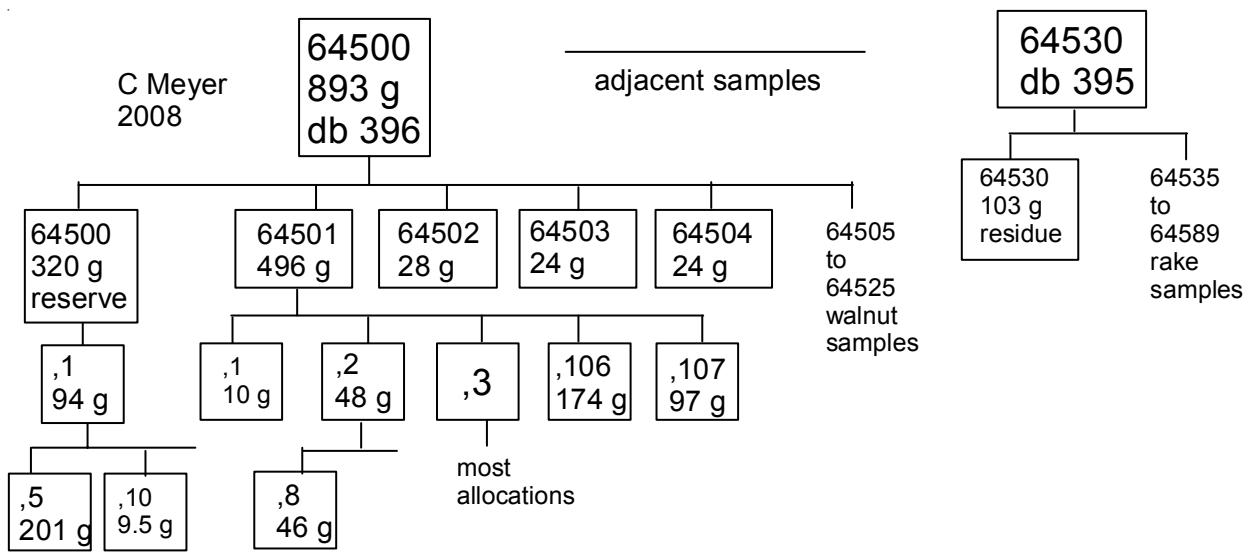


Table 3: Rake Samples from 64530 (DB395)

	weight	Ryder's term	ref
64535	256.6	anorthosite and glass	Jessberger, Morris, See
64536	177.5	anorthosite and breccia	
64537	124.3	cataclastic anorthosite and impact melt	McKinley 1984
64538	30.03	breccia	
64539	17.76	breccia	
64545	14.09	breccia	
64546	12.8	cataclastic anorthosite and impact melt	McKinley 1984
64547	10.9	breccia	
64548	8.49	breccia	
64549	6.47	breccia	
64555	5.29	breccia	
64556	5.15	breccia	
64557	4.79	breccia	
64558	3.13	breccia	
64559	21.8	impact melt	McKinley 1984
64565	14.73	impact melt	McKinley 1984
64566	14.13	impact melt	
64567	13.86	impact melt	
64568	9.78	poikilitic impact melt	
64569	14.32	poikilitic impact melt	
64575	6.84	poikilitic impact melt	
64576	6.92	basaltic impact melt	
64577	5.69	breccia	
64578	6	impact melt	
64579	4.8	impact melt	
64585	4.7	impact melt	
64586	3.3	impact melt	
64587	7.2	breccia	
64588	2.55	breccia	
64589	4.04	cataclastic anorthosite	
64530	102.8	residue	

see also table 2 for walnuts, peanuts



Figure 9: Astronaut collecting rake samples at North Ray Crater. AS16-106-17340. Note that some rather large specimens were collected this way (e.g. 64535).

Table 4. Chemical composition of rake samples.

	64535	64537	64546	64548	64559	64559	64565	64567	64569	64569
reference		McKinley84	McKinley84	Floran76		McKinley84	McKinley84	Hubbard73	Wasson77	Floran76
weight				Ryder 80				Wiesmann76		
SiO ₂ %	see			45.28				45.7	(c)	46.37
TiO ₂	sample	0.8	(a) 0.5	(a) 0.43	0.9	(a) 0.8	(a) 0.7	(b) 1.03	0.94	
Al ₂ O ₃		20.2	(a) 27.7	(a) 27.67	20.7	(a) 21.3	(a) 21.62	(c) 22.48	20.81	
FeO		9.5	(a) 4.6	(a) 4.47	9.4	(a) 8.3	(a) 7.08	(c) 8.5	7.6	
MnO		0.083	(a) 0.056	(a)	0.085	(a) 0.084	(a) 0.07	(c) 0.1		
MgO		11.1	(a) 5.1	(a) 5.67	11.6	(a) 10.8	(a) 11.5	(c) 12.4	11.25	
CaO		12	(a) 16.7	(a) 15.79	12.1	(a) 12.5	(a) 12.52	(c) 11.7	12.35	
Na ₂ O		0.5	(a) 0.46	(a) 0.464	0.506	(a) 0.53	(a) 0.42	(b) 0.504	0.52	
K ₂ O		0.18	(a) 0.07	(a) 0.13	0.19	(a) 0.16	(a) 0.18	(b) 0.2	0.22	
P ₂ O ₅								0.19	(c)	
S %										
sum										
Sc ppm		11.3	(a) 7.2	(a) 6.78	11.3	(a) 10.7	(a)	13.3		
V		29	(a) 19	(a)	32	(a) 27	(a)	40		
Cr		1160	(a) 657	(a) 670	1184	(a) 1115	(a) 1024	(b) 1320		
Co		97	(a) 21	(a) 24.5	94	(a) 68	(a)	59		
Ni		1725	(a) 330	(a) 380	1560	(a) 1140	(a)	930		
Cu										
Zn								3.5		
Ga								4.6		
Ge ppb								2300		
As										
Se										
Rb							4.933	(b)		
Sr							147	(b)		
Y										
Zr							311	(b) 360		
Nb										
Mo										
Ru								77		
Rh										
Pd ppb										
Ag ppb									7	
Cd ppb									4.5	
In ppb										
Sn ppb										
Sb ppb										
Te ppb										
Cs ppm										
Ba	325	(a) 95	(a)		300	(a) 300	(a) 218	(b) 270		
La	29	(a) 8.3	(a) 14.6		29.2	(a) 27.8	(a)	26.2		
Ce	73	(a) 23	(a)		75	(a) 70	(a) 57.9	(b) 63		
Pr										
Nd	46	(a) 15	(a)		47	(a) 42	(a) 35.5	(b) 44		
Sm	13.7	(a) 3.9	(a)		13.8	(a) 12.8	(a) 9.85	(b) 11.3		
Eu	3.78	(a) 1.26	(a)		1.67	(a) 1.57	(a) 1.3	(b) 1.5		
Gd							12.1	(b)		
Tb	2.64	(a) 0.73	(a)		2.63	(a) 2.48	(a)	2.4		
Dy	14.5	(a) 4.4	(a)		15.1	(a) 15.4	(a) 13	(b) 17		
Ho							7.54	(b)		
Er										
Tm										
Yb	8.87	(a) 2.7	(a)		8.96	(a) 8.4	(a) 6.91	(b) 8.7		
Lu	1.29	(a) 0.39	(a) 0.67		1.31	(a) 1.23	(a)	1.2		
Hf	9.4	(a) 2.7	(a)		9.3	(a) 8.9	(a) 11	(b) 8.5		
Ta	1.3	(a) 0.4	(a)		1.2	(a) 1.1	(a)	0.88		
W ppb										
Re ppb										
Os ppb										
Ir ppb	43	(a) 11	(a)		42	(a) 25	(a)	19		
Pt ppb										
Au ppb	38	(a) 9	(a)		36	(a) 25	(a)	20		
Th ppm	4.5	(a) 1.2	(a)		4.3	(a) 4.1	(a)	4		
U ppm	1.1	(a) 0.3	(a)		1.2	(a) 1.2	(a) 1.1	(b) 1.1		

technique: (a) INAA, (b) IDMS

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